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Ion Exchange for the Removal of Nitrate from Well Water

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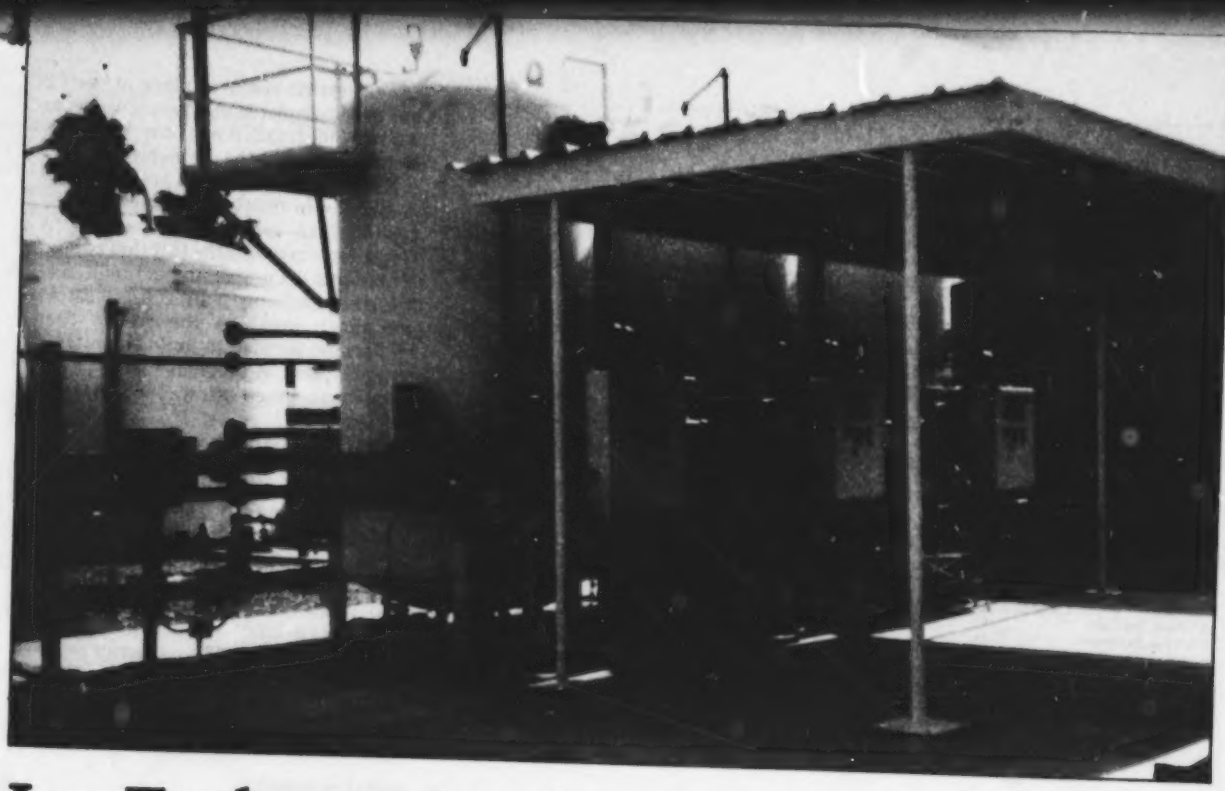
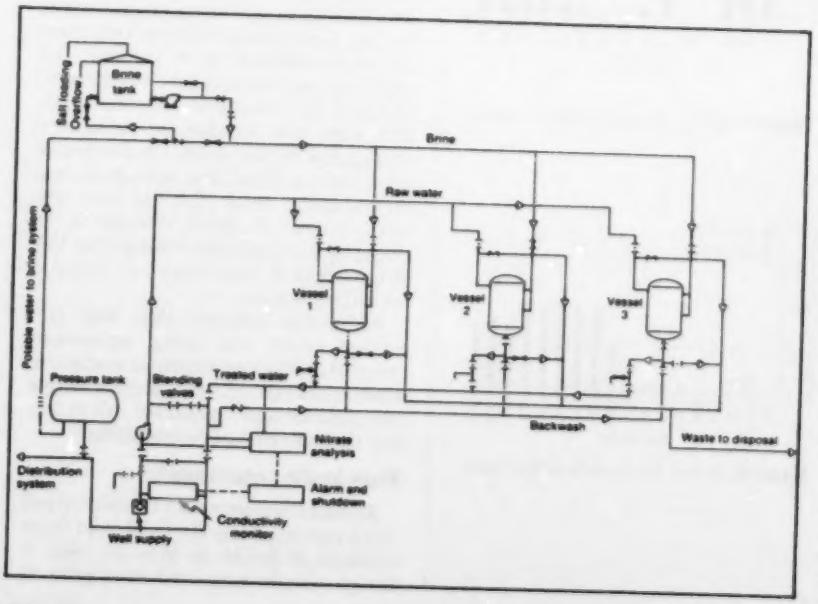


Ion Exchange for the Removal of Nitrate From Well Water

EPA/600/J-86/166
JOURNAL ARTICLE

Richard P. Lauch and Gerald A. Guter

A 1-mgd (3.8-ML/d) ion exchange plant was built in McFarland, Calif., to remove excess concentrations of nitrate from one of the city's supply wells. Data are reported for the semiautomatic mode of operation, during which time the plant has performed satisfactorily. Nitrate has been reduced to less than 10 mg as nitrogen/L and brine has been eliminated from the product water.



A 1-mgd (3.8-ML/d) ion exchange plant was completed in October 1983 by the McFarland (Calif.) Mutual Water Company to remove nitrate from the city's drinking water. McFarland, located about 30 mi (48 km) northwest of Bakersfield in the southern part of the San Joaquin Valley, has a population of approximately 6000 people. The area is extensively agricultural, and nitrogen fertilizers are probably the source of nitrate in the well water. Currently, McFarland's only water source is groundwater. Table 1 shows the composition of the water drawn from McFarland's four wells and shows that three exceed the US Environmental Protection Agency's (USEPA's) maximum contaminant level (MCL) of 10 mg/L for nitrate as nitrogen (NO_3-N).[1] McFarland has been using two wells (1 and 4) with a total capacity of 1400 gpm (88 L/s). Water from well 3 is prohibited for public use because of high nitrate levels.

Shown schematically (left) and in the photograph above, this ion exchange plant is evidence of the increasing levels of nitrate being found in water supplies in California's San Joaquin Valley.

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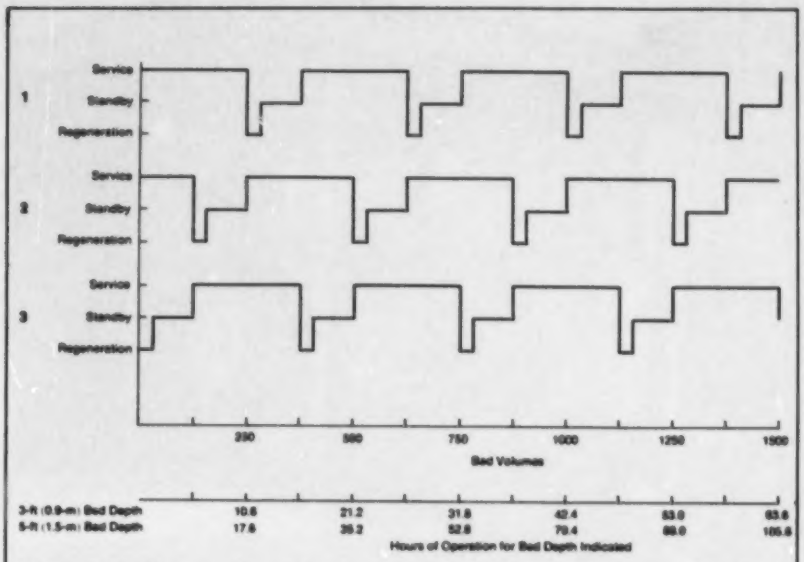

Figure 1. Cyclic operation of the three vessels at 250 gpm (16 L/s) per vessel

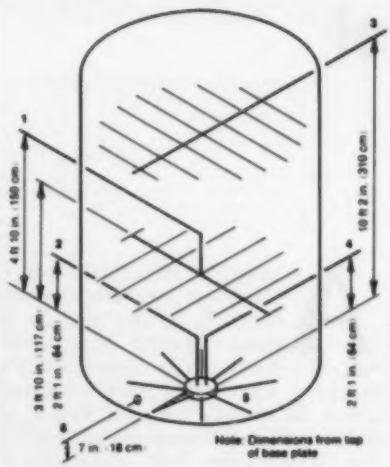

Figure 2. Location of distributors and collectors

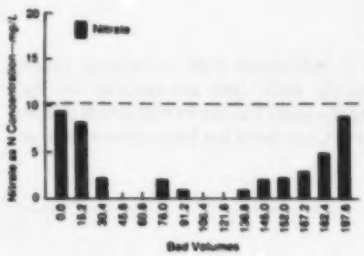

Figure 4. Resin declassification tests

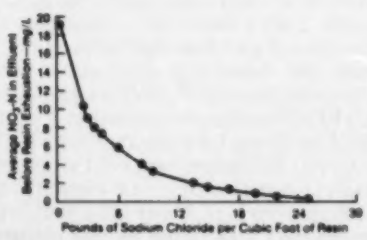

Figure 3. Pilot column ion exchange system nitrate leakage dependence on salt loading *(example using well 3)*

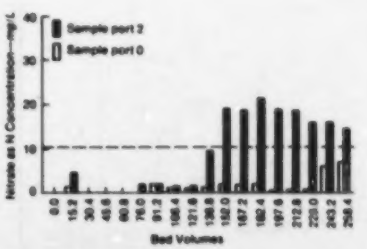

Figure 5. Resin declassification tests

The nitrate removal plant at well 2 has been completed and two new deeper wells (>900 ft [>270 m]) have been constructed to serve the developing areas.

Nitrate concentrations are gradually increasing in many San Joaquin Valley communities—even in deeper wells. This trend, together with the fact that capital costs for a deep well and a 1-mgd (3.8-ML/d) ion exchange plant at this location are about equal, is the reason that McFarland decided to build the nitrate removal plant. A progress report on the plant was given at a 1983 AWWA seminar.[2]

Funds for the plant were furnished by the US Department of Housing and Urban Development through the Kern County Community Development Program Department, by the Kern County Water Agency, and by the McFarland Mutual Water Company. The USEPA also funded a cooperative agreement with McFarland Mutual (September 1981) to obtain cost and performance information on the new plant and to perform additional research on special nitrate-selective resins and on improving the regeneration process.

Initial research

Initial research was begun at McFarland in June 1978 under a cooperative agreement with the Drinking Water Research Division of the USEPA. An engineering consulting firm was hired by McFarland Mutual as part of the agreement to perform the research.

The objectives of the initial study were to perform research and pilot-plant work so that ion exchange, reverse osmosis (RO) and RO followed by ion exchange in series could be compared to determine which process would be the most practical and economical for nitrate removal. The initial study ended in June 1981, and the investigator's conclusion was that the ion exchange process would be best suited as a well-site treatment for nitrate removal at McFarland.[3] Ion exchange can be operated on demand as required by distribution system needs and does not necessitate additional storage and repressurization. Estimated total costs (capital plus operations and maintenance costs [O&M]) from the initial study were $0.18/1000 gal for ion exchange versus $1.00/1000 gal for RO. Brine disposal costs were not included for either process.

Additional research that was performed under the initial agreement resulted in the development of a selective anion exchange resin that prefers nitrate over sulfate[4] and regenerant salt reduction through partial regeneration.

State health requirements

An operating permit for the McFarland plant was issued by the California State Division of Health on May 13, 1983. A design review was conducted prior to

issuance of the permit. The major requirements were:

- Brine must be isolated from the product water with a double-check valve.
- Wash water must be isolated from the product water with block and bleed valves.
- Nitrate levels in the product water must be less than 10 mg NO_3-N/L, preferably less than 7 mg/L.
- The minimum state certification level for the plant operator is class 2.

The double-check valve and block-and-bleed valves were incorporated into the plant. Two McFarland Mutual employees were state-certified as Class 2 operators. The plant design includes automatic monitoring for conductivity on the influent and product water and automatic monitoring for nitrate on the product water. Also, periodic grab samples will be collected and analyzed.

Plant design

Basic design. A simplified schematic of the plant is shown on page 83. The ion exchange plant was located between an existing well pump and pressurized holding tank. The well pump is cycled by a pressure signal from the pressurized tank and, therefore, the water is treated on an as-needed basis. The plant is designed to treat 1 mgd (3.8 ML/d), but normal operation will be to treat part of the water and blend it so that the total well production is 1 mgd (3.8 ML/d) with a nitrate concentration that is less than 10 mg NO_3-N/L.

The plant consists of three reaction vessels that are 6 ft (1.8 m) in diameter and 10 ft (3 m) high. Each vessel was designed to contain either a 3- or 5-ft (0.9- or 1.5-m) bed depth of anion exchange resin. Initially each vessel was charged with 3 ft (0.9 m) of an anion exchange resin.* The three vessels were designed to operate in a staggered fashion, as shown in Figure 1. For example, when one freshly regenerated vessel begins its service mode, another vessel will be half exhausted, and the third vessel will start regeneration. Hence, two vessels are always in the service mode and the third is in the regeneration or standby mode. Table 2 gives the bed characteristics, target flows, and operating conditions for a 3-ft (0.9-m) bed depth.

The plant is currently treating 500 gpm (32 L/s) and blending with 200 gpm (13 L/s) to give a total product flow of 700 gpm (44 L/s). Therefore, each vessel is treating 250 gpm (16 L/s) and the empty bed contact time for each vessel is 2.54 minutes. Table 3 shows the number of regenerations per vessel per day for different operational conditions. The plant is currently treating approximately 70 percent of the total water flow and, therefore, each vessel is regenerated 1.47

*A-101-D, Duolite, Rohm and Haas Co., Philadelphia, Pa.

TABLE 1

*Composition of McFarland well water**

Parameter	Well 1 Sampled 5/8/80	Well 2 Sampled 4/9/80	Well 3 Sampled 5/1/80	Well 4 Sampled 4/1/80
Calcium	28	88	156	78
Sodium	50	65	100	72
Bicarbonate	88	102	121	95
Chloride	28	86	94	51
Sulfate	51	105†	310	182
Nitrate-N	6.8	15.1†	22.1	10.6
Total dissolved solids	235	466	827	485
pH units	7.7	7.2	7.3	7.7

*All measurements except pH are in milligrams per litre.
†Analyses on 5/31/78 showed a sulfate level of 261 mg/L and a nitrate level of 17.6 mg/L.

TABLE 2

Bed characteristics and target flows for a 3-ft (0.9-m) bed depth

Bed cross section area	27.7 sq ft (2.6 m²)
Bed depth	3 ft (0.9 m)
Bed volume	85 cu ft, 635.8 gal (2.4 m³, 2406 L)
Approximate saturated brine concentration	2.6 lbs/gal (259 g/L)
Saturated brine rate	12 gpm (0.76 L/s)
Brine rinse duration	15 minutes
Diluted brine rate	63.5 gpm (4 L/s)
Bed volume of 6 percent brine at above parameters	1.5
Slow rinse rate	64 gpm (4 L/s)
Slow rinse duration	30 to 50 minutes
Declassification rate	5 gpm/sq ft; 140 gpm (3.4 mm/s; 9 L/s)

Current operating conditions

Total product water	700 gpm (44 L/s)
Quantity treated	500 gpm (32 L/s)
Quantity treated per vessel	250 gpm (16 L/s)
Bed volume treated per regeneration	250
Salt use (500 gpm [32 L/s], continuous)	2162 lb/day (981 kg/day)
Service loading rate (250 gpm)	9.03 gpm/sq ft (6 mm/s)
Contact time	2.54 minutes
Nitrate-N influent	16 mg/L
Nitrate-N product	6.2-8.3 mg/L

TABLE 3

Frequency of regeneration

Resin Bed Depth and Percent Capacity	Number of Regenerations per Vessel per Day — Bed Volume 200	250	300	400
100-Percent capacity				
3-ft (0.9-m) Depth	2.62	2.10	1.75	1.31
5-ft (1.5-m) Depth	1.57	1.26	1.05	0.79
70-Percent capacity				
3-ft (0.9-m) Depth	1.83	1.47*	1.23	0.92
5-ft (1.5-m) Depth	1.10	0.88	0.74	0.55
50-Percent capacity				
3-ft (0.9-m) Depth	1.31	1.05	0.88	0.66
5-ft (1.5-m) Depth	0.79	0.63	0.53	0.40

*Current operating condition

TABLE 4

*Chemical analysis of untreated, treated, and blended water**

Constituent	Untreated†	Treated	Blended
Calcium	94	98	96
Magnesium	2.1	2.1	2.1
Sodium	68	68	68
Potassium	3.8	3.5	3.8
Bicarbonate	119	27.7	120
Chloride	88.2	264	166
Sulfate	120	<5	40
Nitrate-N	16	2.6	6.6
Color units	1	1	1
Odor	none	none	none
pH units	7.2	7.4	7.4
Electrolytic conductivity—μmho/cm	790	920	850

*All units are milligrams per litre unless indicated otherwise.
†Iron = <0.05 mg/L, manganese = <0.01 mg/L

times per day when the plant runs continuously. There are times when the plant will turn off because of low water demand, such as during the early morning hours.

Plant control. The plant is controlled by a microprocessor, which receives a totalized flow signal from each vessel and automatically cycles the vessels (Figure 1). The cycle will be interrupted if the main pump shuts off because of low demand, but the system will resume automatically when demand increases. The microprocessor also receives signals of product water nitrate concentration and conductivity, and automatically shuts off the system if NO_3-N is greater than 10 mg/L or if effluent conductivity is greater than influent conductivity. A periodic print-out of these readings is also given. When the system is operating automatically, an operator is required to check the plant only once a day.

Plant size. The plant was designed so that the three vessels can operate with either 3 or 5 ft (0.9 or 1.5 m) of resin. Both bed depths will be tested at McFarland. If a 3-ft (0.9-m) depth is satisfactory, smaller vessels can be used for future plants. The inlet brine distributor (shown attached to pipe 1 in Figure 2) can be rotated 180 degrees to accommodate either bed depth of resin.

The advantages of a 3-ft (0.9-m) bed depth are: (1) lower initial costs because the vessels would be smaller (6 ft [1.8 m] high instead of 10 ft [3 m]) and (2) a smaller charge of resin would be used. The advantages of a 5-ft (1.5-m) bed depth are: (1) longer service periods between regenerations, (2) extra capacity for the remaining two vessels if one must be taken off line for repair, and (3) longer resin life because of less frequent regeneration.

The initial pilot-plant study confirmed that a 3-ft (0.9-m) bed depth will give sufficient contact time for the exchange reaction to take place and that the in across a 5-ft (1.5-m) bed depth would be less than 3 psi (21 kPa), which is insignificant.

Brine disposal. Brine is disposed of at the municipal wastewater treatment plant, which consists of three aeration lagoons. Effluent is discharged to 128 acres (51 ha) of agricultural land that is used to grow animal feed crops and cotton. State approval for discharging the brine to the municipal plant has been granted. Municipal wastewater, soil, and groundwater samples, taken before and after the ion exchange plant went on line, will be compared to determine whether another disposal method, such as a lined evaporation pond, will be necessary.

Plant operation

Automation. McFarland's nitrate removal plant began semiautomatic opera-

TABLE 5

Operational data for one cycle of one vessel

Label of Data	Run Data	Bed Volumes	Nitrate-Nitrogen Port 0	Nitrate-Nitrogen Port 2	Calculated Parameter	Calculated Value
Run number	11093-p3	000.0	000.0	000.0	meq NO_3 removed per litre resin	270.07
		0.0	0.0	0.0		
Resin	A 101D	0.0	0.0	0.0		
		15.2	1.4	4.56		
Well	2	30.4	0.0	0.0	meq Cl used per litre resin	1499.79
Resin—*gal (L)*	636 (2407)	45.6	0.0	0.0		
		60.8	0.0	0.0		
		76.0	0.0	1.99	meq Cl used per meq NO_3 removed	5.55
		91.2	1.99	1.99		
		106.4	1.13	1.45		
6% Brine—*gal (L)*	954 (3610)	121.6	0.99	1.58	Bed volume × NO_3 breakthrough	259.4
		136.8	1.4	9.53		
Influent		152.0	1.99	19.08		
NO_3-N—*mg/L*	16.0	167.2	1.9	18.67	meq SO_4	2.50
		187.4	1.99	21.27		
		197.6	0.41	18.79		
Influent		212.8	0.59	18.47	meq NO_3	1.14
SO_4—*mg/L*	120	228.0	0.45	15.69		
		243.2	5.96	15.9	meq S + N	3.64
		258.4	6.95	14.5		
		259.4	10.16	14.5	per litre influent	
Influent Cl—*mg/L*	88.2					
Influent HCO_3—*mg/L*	119				NO_3 removed—*mg/L* (average before breakthrough)	14.33
Number of brine fractions	partial					
Run format					NO_3 leakage—*mg/L* (average before breakthrough)	1.67

TABLE 6

*Nitrate-nitrogen concentrations for repeat runs at a given number of bed volumes treated**

6% Brine *gal (L)*	Date of Sampling	Unit	NO_3-N Concentration per Bed Volume Treated *mg/L* 0	91	182	212	228	242	260
991 (3751)	4/24/84	1	2.0	2.7	2.7	5.2	6.8	6.8	7.2
954 (3611)	4/26/84	2	2.3	1.1	2.7	3.4	8.6	9.0	9.5
1245 (4713)	4/26/84	3	0.7	1.4	9.9	8.8	8.8	8.8	8.8
970 (3672)	4/27/84	1	2.3	2.5	4.3	4.7	5.0	5.6	6.8
1176 (4452)	4/30/84	2	3.2	2.3	4.3	5.0	4.7	5.0	6.8
938 (3550)	5/1/84	3	1.6	2.3	4.3	4.3	5.2	6.1	7.0
842 (3187)	5/2/84	1	3.4	5.0	4.5	3.8	5.4	6.8	7.5
927 (3510)	5/3/84	2	5.4	5.6	2.9	4.1	5.2	6.1	6.3
901 (3411)	5/4/84	3	2.9	2.0	4.7	5.4	5.4	6.3	7.2
895 (3388)	5/7/84	1	2.5	2.3	3.2	4.1	5.2	5.4	5.6
869 (3290)	5/9/84	2	3.4	2.0	4.5	5.2	5.0	5.4	5.6
779 (2949)	5/9/84	3	4.1	2.3	3.6	5.4	6.1	7.7	7.9
1028 (3891)	5/11/84	1	4.3	2.3	2.9	6.3	5.6	6.1	6.3
938 (3550)	5/11/84	2	2.0	2.5	5.4	6.1	6.3	6.1	5.9
938 (3550)	5/15/84	3	4.5	2.3	3.4	3.6	3.8	4.5	5.0
1001* (3789)	5/16/84	1	2.0	2.7	2.7	3.2	3.4	3.8	5.0
885* (3350)	5/17/84	2	2.9	2.5	2.7	2.9	3.2	3.2	3.8
938* (3551)	5/18/84	3	3.6	3.4	2.7	3.6	3.8	4.5	5.6

*Influent NO_3-N = 16 mg/L

TABLE 7

1983 Capital costs

Item	Operating Cost for Different-Size Vessels—$ 6-ft (1.8-m) Diameter × 6-ft (1.8-m) Height	6-ft (1.8-m) Diameter × 10-ft (3-m) Height*
Ion exchange vessels (three included)	96 511	111 741
On-site construction	81 151	81 154
Brine tank	18 700	18 700
Other	40 045	40 045
Resin—225 cu ft (6.4 m³), 3-ft (0.9-m) depth	35 000	
Resin—424 cu ft (12 m³), 5-ft (1.5-m) depth		56 610
Subtotal	271 407	308 250
Engineering and administration—15 percent	40 711	46 388
Total	312 118	354 638

*McFarland's plant

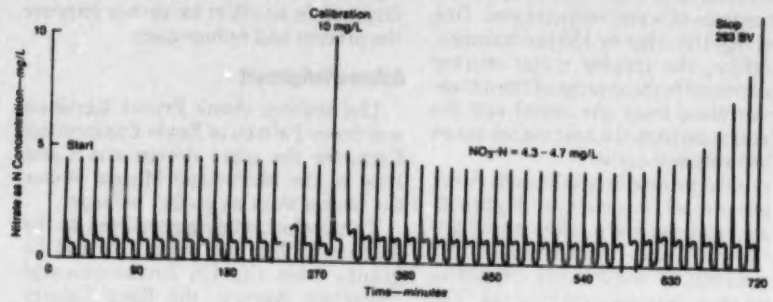

Figure 6. Typical nitrate breakthrough curve

TABLE 8
Cost detail for equipment and construction

Parameter	Cost—$
Three ion exchange vessels—6-ft (1.8-m) diameter × 6-ft (1.8-m) height	96 511
Three ion exchange vessels plus 4 ft (1.2 m) added height	8 375
plus walkway and ladder	6 855
Subtotal ion exchange vessels	111 741
Sewer, catch basin	6 156
Electrical and sample conduits	2 166
Concrete pads	6 400
Booster pump	3 651
Brine pump	1 227
Air compressor	2 073
Steel piping	13 900
Flow, conductivity meters	15 795
PVC piping	4 667
Above-ground electrical	20 603
Set ion exchange units, connect	1 448
Set brine tank	868
Miscellaneous	2 200
Subtotal on-site construction	81 154
Brine tank	17 527
Delivery	1 173
Subtotal brine tank	18 700
Other	
Control panel	7 614
Ion chromatograph	12 455
Control enclosure	9 833
Programmable controller	10 143
Subtotal other	40 045

TABLE 9
Operation and maintenance costs

Item	Annual Costs—$	$/1000 gal
Operator—*1 h/day*	4 745	0.013
Normal O&M—2% ($354 638)	7 113	0.019
Power, booster pump—0.12 hp-h (0.093/kW-h)	8 140	0.022
Resin replacement—5 years	11 522	0.032
Salt—($31.50/ton), 70 percent capacity	12 429	0.034
Miscellaneous	3 000	0.008
Total O&M costs	46 949	0.128

TABLE 10
Total cost of plant and comparison with current cost of water in McFarland, Calif.

Cost Item	Annual Costs—$	$/1000 gal
Plant		
Capital costs—$354 638 (20 years at 10%)	41 773	0.114
Operation and maintenance	46 949	0.128
Total	88 722	0.242
Current water costs		
First 11 000 gal (41 639 L)		0.980
Over 11 000 gal (41 639 L)		0.468

tion in October 1983. The plant is now fully automated but the data in this report were collected under semiautomatic operation. The plant has been operating 4 to 8 hours per day using the same sequence of events that will occur under full automation. Under semiautomatic operation, an operator is required to actuate push-button switches that start the service and regeneration modes for each vessel. The plant has been operating as described in the plant design section of this article. The three vessels are currently charged with a 3-ft (0.9-m) depth of resin. The vessels cycle as shown in Figure 1, which demonstrates that at this bed depth each vessel is treating 250 bed volumes in 10.6 hours. One of the three vessels changes from the service mode into the regeneration mode every 5.3 hours. This sequence stops when the plant is turned off by the operator or because of low demand. The cycling sequence for the three vessels resumes when the plant operation is reinstated.

The operational sequence of events for each vessel is (1) service, (2) regeneration, (3) slow rinse, and (4) resin declassification (mixing).

Figure 2 shows the arrangement of the distribution manifolds within each vessel. Service flow enters the vessel in the downflow direction through distribution pipe 3 and exits through manifold 5. Manifold 5 has holes on the bottom of the spider arms so that flow is collected from the very bottom of the tank to eliminate dead volume. Regeneration flow enters in the downflow direction through distributor 1 and exits through manifold 5. Slow-rinse water enters through distributor 1 and exits through manifold 5. Resin declassification water enters through either pipe 2 or 4 and flows out through half of manifold 5 in the upflow direction. Manifold 5 is split so that pipes 2 and 4 each feed half of the manifold. The best procedure for declassification at the current brine dosage of 1.5 bed volumes of 6-percent sodium chloride (NaCl)—1.5 L of 6 percent NaCl/L of resin)—is to let water flow in the upflow direction through half of manifold 5 for 3 minutes and then let the bed settle for 3 minutes. This is done twice for one side of the manifold and once for the other side.

Resin declassification. After the resin bed is backflushed and expanded in the conventional manner, the resin beads will always settle the same way—the heavier beads will end up at the bottom of the vessel. Therefore, resin declassification (mixing) is necessary when partial regeneration is used, because resin beads at the effluent end of the vessel would otherwise remain in the nitrate form after regeneration and cause increased nitrate in the product water when the vessel is returned to service. Partial

regeneration is being used at the McFarland ion exchange plant in order to reduce the salt cost.

Figure 3 shows that a considerable reduction in salt usage is accomplished if some nitrate leakage into the treated water can be tolerated. McFarland is operating with a nitrate leakage of 2-5 mg NO_3-N/L into the treated water. When this is blended with 30 percent untreated water (16 mg NO_3-N/L), the nitrate concentration in the final product water ranges from 6.2 to 8.3 mg NO_3-N/L.

Figure 4 shows an example of increased nitrate concentration at the beginning of service because the resin was not properly declassified. Figure 5 shows an example of satisfactory resin declassification. The open bars in Figure 5 depict nitrate concentration from the effluent of the ion exchange vessel, and the solid bars show nitrate concentrations from samples that were collected 19 in. (0.5 m) above the bottom of the resin bed.

Plant performance

A chemical analysis of untreated, treated, and blended product water is given in Table 4, which shows that NO_3-N was being reduced from 16 to 2.6 mg/L in the treated water and that the blended product water contained 6.6 mg NO_3-N/L. Blended product water was made up of 70-percent treated and 30-percent untreated water. Chloride concentration in the blended product water increased from 88.2 to 166 mg/L; the sulfate concentration decreased from 120 to 40 mg/L. The USEPA secondary regulation[5] for both chloride and sulfate concentration specifies an MCL of 250 mg/L, and Table 4 shows that neither of these ions exceeds that level in the blended product water. Bicarbonate is exchanged for chloride for a short period after the resin is regenerated, which explains the low level of bicarbonate in the treated water. Table 4 shows that iron and manganese concentrations were very low in the untreated water and did not present a problem.

Table 5 shows typical data during a cycle for each vessel. The table shows that 1.5 L of 6-percent brine was used per litre of resin (3610:2407), and 5.55 milliequivalents of chlorine per milliequivalent of nitrate removed was required for regeneration. The plant would use 2162 lb (981 kg) of salt per day if operated continuously. During the run, this vessel removed 270.07 milliequivalents of nitrate per litre of resin. The average NO_3-N removed before breakthrough was 14.33 mg/L; average leakage was 1.67 mg NO_3-N/L.

Results of repeat runs are given in Table 6. These runs were made with two vessels operated in a staggered fashion. The system was operating in the semiautomatic mode for a period of 4 to 8 hours per day. The system was turned off when an operator was not present. Each vessel was regenerated after 260 bed volumes of water were treated. One vessel lags the other by 130 bed volumes. Therefore, the treated water nitrate concentration is the average of the nitrate concentration from one vessel and the concentration from the next vessel, taken 130 bed volumes earlier.

A typical nitrate breakthrough curve for one vessel is given in Figure 6. Nitrate readings were taken automatically every 15 min. Approximately 283 bed volumes of water were treated to clearly show nitrate breakthrough. The large peak in the middle of the run represents a nitrate calibration concentration of 10 mg NO_3-N/L. The smaller peaks, which are proportional to the calibration peak, show that the NO_3-N concentration of the treated water from the vessel ranged from 4.3 to 4.7 mg/L until nitrate breakthrough.

Plant costs

Capital costs for McFarland's plant are summarized in Table 7. Costs are given for two different vessel sizes: 6-ft diameter × 6-ft height (1.8-m diameter × 1.8-m height) and 6-ft diameter × 10-ft height (1.8-m diameter × 3-m height). The second column gives costs for the plant with three vessels and 10-ft (3-m) side height that was built at McFarland. Table 8 gives the detailed capital costs breakdown. Some costs that were necessary for the prototype, such as an ion chromatograph and a control enclosure that houses a small laboratory, may not be necessary for future systems.

Estimated operation and maintenance costs are given in Table 9. The operator cost was estimated to be 1 hour per day when the plant is fully automatic. Resin replacement and salt costs are the largest constituents of the O&M costs. The total O&M costs from Table 9 were 12.8 cents/1000 gal. Capital costs were 11.4 cents/1000 gal when amortized at 10 percent over 20 years (Table 10). Therefore, the total cost for this system is 24.2 cents/1000 gal (Table 10). Table 10 also compares consumers' water costs in McFarland with the cost of nitrate removal for the new plant.

Summary

A full-scale 1-mgd (3.8-ML/d) demonstration plant, using ion exchange for the removal of nitrate from well water, was built at McFarland, Calif. The plant has been performing satisfactorily in the semiautomatic mode since October 1983. Full automation of the plant was completed in June 1984. State requirements of reducing nitrate levels below 10 mg NO_3-N/L and eliminating brine from the product water have been met. Total costs for the plant, including capital and operations and maintenance, were 24.2 cents/1000 gal. Research is continuing at McFarland on nitrate-selective resins, regenerant reuse, monitoring, and brine disposal, in an effort to further improve the process and reduce costs.

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